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ADP010988

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Correlates of Load Carriage Performance Among Women

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Summary

To examine correlates of the speed at which female soldiers carrying loads could cover ground on foot, 12 volunteers (mean±SD: 25.3±6 years, 166±7 cm, 61.3±7 kg) were timed over 3.2 km while carrying loads of 14, 27, and 41 kg. Respective course times were 25.7±3, 30.7±4 and 36.9±5 min, which differed significantly ($p<0.05$) from each other. A correlation analysis with independent variables of body mass, bitrochanteric diameter, hip circumference, shoulder diameter, height, age, relative $\dot{V}O_{2\ max}$ (ml/kg/min), absolute $\dot{V}O_{2\ max}$ (l/min), percent body fat, fat free mass, and self-reported scores on the Army fitness test (pushups, situps and 3.2 km run) revealed that absolute $\dot{V}O_{2\ max}$ and 3.2 km run time were the best predictors of loaded 3.2 km run time for each load. Correlation coefficients for the 14, 27 and 41 kg load course times respectively were -0.64, -0.61 and -0.70 for absolute $\dot{V}O_{2\ max}$ and 0.80, 0.67 and 0.75 for the 3.2 km run time. For the 14 and 27 kg loads there were no anthropometric measurements that correlated well with run time. However, with the 41 kg load, there were good relationships ($p<0.1$) between 3.2 km run time and body mass ($r=-0.59$), height ($r=-0.55$), hip circumference ($r=-0.52$) and fat free mass as determined from skin folds ($r=-0.56$). This suggests that larger subjects with greater muscle mass, for whom the 41 kg load represented a smaller percentage of their bodyweight, were able to carry the heaviest load faster than smaller, less muscular subjects.

Introduction

When motorized vehicles are unavailable, incapable of traversing the terrain, or easily detectable by the enemy an army must depend on soldiers to carry loads in the field. Success at accomplishing a mission and survival on the battlefield is dependent in part on the speed at which a unit of foot soldiers can cover ground while carrying a load. However, the unit's speed is limited by the speed of its slowest member. Thus, a screening tool that would allow selection of soldiers likely to be capable of the desired load carriage speed would contribute to the effectiveness of the fighting force. For safety and convenience, a screening battery based on easily measured anthropometric, aerobic endurance, and muscular endurance variables is preferable to actual load carriage tests.

In this study female soldiers served as the research subjects. It is important to study the ability of women to perform combat-related tasks because 1) during basic training, all female recruits currently participate in load carriage marches and other combat maneuvers, 2) women have been well integrated into combat-support military occupational specialties (jobs) and they could easily become involved in combat if front lines shift or the enemy infiltrates behind our lines (this happened during the Gulf War).

Studies in which physiological and anthropometric determinants of load carriage performance (LCP) have been examined were undertaken mainly by military groups. Maximal oxygen uptake ($\dot{V}O_{2\ max}$) was found to be one of the best predictors of LCP in several studies (7, 13, 22, 21). The role of fat free mass was found to have a large influence as well (13, 21, 16). No statistically significant correlations were found between % body fat and LCP in any of the studies reviewed, suggesting that an increase in % body fat does not adversely affect performance in a non-obese physically fit cohort. Unloaded 3.2 km run time was a fairly good predictor of LCP ($r=0.60$-0.63) in two separate studies by Kraemer et al. (15 and 14). In only three

Paper presented at the RTO HFM Specialists' Meeting on "Soldier Mobility: Innovations in Load Carriage System Design and Evaluation", held in Kingston, Canada, 27-29 June 2000, and published in RTO MP-056.

previous studies was the impact of load carriage on female subjects examined (14, 22, 21). LCP has been assessed in previous studies using a relatively narrow range of loads.

This paper is based on analysis of data from an experiment designed to compare the physiological, biomechanical, and maximal performance effects of two different backpack systems on female soldiers carrying three different loads (11). The purpose of the current paper is to describe how anthropometric and aerobic endurance measures related to backpack load carriage performance of females on a 3.2 km load carriage course. The study is unique in several aspects. Load carriage data from females is limited, especially at the 3.2 km distance, and in only one other study was LCP using 3 different loads examined. In the present study, the heaviest load used for the 3.2 km test was greater than in any previous study reported for women.

Methods

The volunteers for this study were 12 female soldiers who were medically screened and from whom written informed consent was obtained prior to their participation. Several had sedentary jobs, but most had jobs that were physically demanding, such as Military Police work.

Subjects were tested under three load conditions. The “fighting load” weighed 14.2±0.59 kg (31 lb) and consisted of the Battle Dress Uniform (BDU), boots, body armor, Kevlar® helmet, equipment belt, load-carriage vest, dummy grenades, ammunition clips, and M-16 rifle. The “approach load” included the fighting load plus 13.6 kg of weight in a backpack, totaling 27.2±1.2 kg (60 lb), while the “sustainment load” included the fighting load plus 27.2 kg of weight in a backpack, for a total of 40.6±1.1 kg (90 lb). The weight in a pack consisted of steel plates, sandbags, or containers filled with small metal objects, held in place in the pack with foam blocks. The backpacks used in testing were external-frame Army packs.

The location of the center of mass of a backpack had been shown in one of our previous experiments to affect energy cost by as much as 24% (19). The study showed that the best placement of the pack center of mass for efficient load carriage was as close as possible to the back and as high as possible in the pack. This guideline was used for the present study. The center of mass of the 14 kg load system was actually just in front of the subject (due to placement of the magazines and grenades on the front of the load carriage vest). For the 27 kg load, the center of mass was slightly in front of the frame of the backpack, and for the 41 kg load, it was slightly behind the frame and a bit higher than for the 27 kg load. These center of mass locations do not take into account the weapon carried in the hands in front of the body, which would bring the load center of mass even further forward.

The loads selected for the study are similar to those cited in the U.S. Army field manual on foot travel (4). It states that up to 72 lb may be carried on "prolonged dynamic operations" and that "circumstances could require soldiers to carry loads heavier than 72 lb, such as approach marches through terrain impassable to vehicles or where ground/air transportation resources are not available. These ... loads can be carried easily by well-conditioned soldiers. When the mission demands that soldiers be employed as porters, loads of up to 120 lb can be carried for several days over distances of 20 km a day" and "loads of up to 150 lb are feasible.” Soldiers in actual combat operations have often reported carrying loads well in excess of 100 lb (45 kg).

Dependent Variables

Because the speed at which a soldier can move when approaching and traversing the battlefield can greatly affect the outcome of a battle, one means of evaluating soldier performance is to time simulated versions of this type of movement. Thus the research volunteers were timed carrying various loads as they traveled 3.2 km by foot as fast as they could.

Subjects traversed at maximal speed a 3.2 km paved course that included four small hills. Each soldier was instructed to give her best effort in completing the 3.2 km distance in the fastest possible time. The volunteers performed this test six different times, carrying each of the three different loads twice, with at least 2 days of rest between adjacent trials. Each subject was accompanied by a test technician who was responsible for helping the volunteer in the event of injury, making any pack adjustments that became necessary en route, ensuring the test route was accurately followed, and providing encouragement.

Soldiers performed 2 trials with each of the 3 loads (14, 27, and 41 kg) on the 3.2 km course. The volunteers carried the different loads in a balanced order so that no load was more likely than another to be tested in any particular part of the testing order. Each pair of same-load trials, which did not differ significantly from each other, was averaged before statistical analysis was performed. Correlation analyses and stepwise multiple regressions were performed to determine if anthropometric and aerobic endurance variables related to 3.2 km run time with the 3 different loads.

Independent Variables

Maximal oxygen uptake. Oxygen uptake was measured using a continuous, grade-incremental, treadmill protocol and a computerized expired-gas collection, analysis system custom-developed at USARIEM. To ensure the safety of the volunteer, the output of a single lead (V_5) electrocardiograph was monitored during the entire test by trained personnel. Volunteers were connected to the gas collection apparatus via a mouthpiece, large 2-way Hans Rudolph valve, and flexible tubing supported by an overhead support-arm. The gas analysis system incorporated a KL Engineering air-flow turbine, an S-3A oxygen analyzer, an LB-2 carbon-dioxide analyzer, a Yellow-Springs thermister, a Hewlet-Packard electronic square wave counter, and a Hewlett-Packard desktop computer and printer which determined and printed, at pre-selected intervals, the rate of oxygen consumption and ventilation per minute expressed both in absolute terms (L/min) and relative to the individual's body mass (ml/kg/min). The volunteer first warmed up by running for 5 minutes at 5 miles per hour with the treadmill bed horizontal. After a 5 minute rest, the volunteer remounted the treadmill and started running at a speed determined to be moderate based on her heart rate response during the warm-up run. The treadmill grade was set at a 5 percent incline at this time. At 3 minute intervals, the treadmill grade was increased by 2 percent without changing the treadmill speed. A volunteer was considered to be at maximal oxygen uptake if, 3 minutes after a grade increase, she had not increased oxygen uptake by at least 2.0 ml/kg/min. The volunteers generally reached maximum oxygen uptake on the treadmill within 10-12 minutes after starting the test. The mouthpiece was inserted for the last 90 seconds of each 3-minute interval and oxygen uptake was calculated and printed every 30 seconds.

Physical fitness. All soldiers are required to take the Army Physical Fitness Test (APFT) twice a year. The self-reported results of the volunteers' most recent physical fitness tests were analyzed to determine if they were useful predictors of load carriage performance. The three components of the test are the maximum number of sit-ups that can be done in 2 minutes, the maximum number of push-ups that can be done in 2 minutes, and time taken to run 3.2 km. Using worksheets published by the Department of the Army (5) absolute scores on the three subtests are assigned points based on the soldier's age and sex, and points for the three subtests are added to get the total APFT score. An advantage of using APFT test data is that soldiers train for the test and try to do well because a good score increases their chances of promotion. Although one might question the accuracy of self-reported data, we felt that the self-reported values were reasonably accurate because the self-reported 3.2 km run time correlated well with times for the loaded 3.2 km run. It is unlikely that soldiers would forget their most recent APFT scores, since it is of such importance in the military environment.

Anthropometric measures. The following variables were also evaluated as predictors of load carriage performance: age, height, bodyweight, biacromial and bitrochanteric diameters, hip circumference, percent body fat determined from equations by Durnin and Womersley (6) using skinfolds, and lean body mass.

Results

Volunteer Characteristics

Table 1 presents the descriptive characteristics of the 12 women who participated in this study.

Table 1. Descriptive Characteristics of Subjects

Variable	Mean ± SD	Range
Age (yr)	25.3±5.5	19.4-38.2
Height (cm)	166.0±6.5	154.7-174.8
Body mass (kg)	61.3±6.7	52.5-72.0
Body fat (%)	25.7±3.22	20.6-31.5
Fat free mass (kg)	45.5±3.7	41.3-50.9
Shoulder diameter (cm)	37.0±1.4	35.2-40.2
Hip diameter (cm)	32.2±2.1	29.6-36.7
$\dot{V}O_{2\,max}$ (ml/kg/min)	48.8±4.6	41.9-54.4
$\dot{V}O_{2\,max}$ (L/min)	3.0±0.5	2.4-3.7
3.2 km run time (min)	17.0±1.1	14.7-18.3
Push-ups (#)	41±12	26-64
Sit-ups (#)	68±10	54-85
APFT score (pts)	256±24	216-290

Table 2 shows that as load increased, time to complete the 3.2 km course also increased. Soldiers took 19% more time to cover the distance with the 27 kg load than with the 14 kg load, and 44% more time to cover the distance with the 41 kg load than with the 14 kg load. There was a strong tendency for volunteers who did well with one load to do well with the other loads. Course times with the 14 and 27 kg loads produced a coefficient of correlation of 0.65. Course times with the 14 and 41 kg loads produced a coefficient of correlation of 0.50, while course times with the 27 and 41 kg loads produced a coefficient of correlation of 0.80. Thus, as expected, course times with more similar loads were more closely related.

Table 2. 3.2 km Load Carriage Course Times (min)

Load	mean (SD)	Range
14 kg	25.7±2.6	20.0 – 29.6
27 kg	30.7±3.7	24.5 – 38.3
41 kg	36.9± 4.8	28.6 – 44.6

Course times with the different loads differed significantly ($p<0.05$)

Correlation coefficients of various independent measures with 3.2 km load carriage course time are seen in Table 3. Absolute $\dot{V}O_{2\,max}$ and 3.2 km run time were the best predictors of course time. The coefficients of correlation between $\dot{V}O_{2\,max}$ (L/min) and 3.2 km time for soldiers carrying the 14, 27, and 41 kg loads, respectively, were -0.64, -0.61 and -0.70. The negative correlations indicate that subjects with higher absolute $\dot{V}O_{2\,max}$ took less time to cover the course. The coefficients of correlation between APFT 3.2 km run time and 3.2 km load carriage time were 0.80, 0.67, and 0.75 for soldiers carrying the 14, 27, and 41 kg loads respectively. All these correlations were statistically significant ($p<0.05$).

Table 3. Correlation Coefficients of Various Independent Measures with 3.2 km Load Carriage Time

Dependant variable	14 kg load	27 kg load	41 kg load
Body mass (kg)	-0.45	-0.42	-0.59*
Height (cm)	-0.29	-0.50#	-0.55#
Hip circumference (cm)	-0.42	-0.36	-0.52#
Fat mass (kg)	-0.41	-0.29	-0.53#
Fat free mass (kg)	-0.41	-0.47	-0.56#
$\dot{V}O_{2\,max}$ (ml/kg/min)	-0.56#	-0.53#	-0.51#
$\dot{V}O_{2\,max}$ (L/min)	-0.64*	-0.61*	-0.70*
3.2 km run time	0.80*	0.67*	0.75*
Push-ups (#)	-0.24	-0.29	-0.09
Sit-ups (#)	-0.28	-0.18	0.49
APFT score (pts)	0.02	0.33	0.19

*$p<0.05$
#$p<0.1$

For the 14 kg load, no anthropometric measurements correlated well with run time. With the 27 kg load, height showed a -0.50 correlation with course time, meaning that taller volunteers tended to be faster. However, with the 41 kg load, greater body size was associated with faster course time (body mass: $r=-0.59$, $p<0.05$; height: $r=-0.55$, $p<0.06$; hip circumference: $r=-0.52$, $p<0.08$; and skinfold determined fat free mass: $r=-0.56$, $p<0.06$). This suggests that the larger subjects with greater muscle mass were able to carry the heaviest load faster. It appears that the heavy pack slows the speed of larger, more muscular subjects to a lesser degree than it does for the smaller, lighter subjects, because the 41 kg load represents a smaller percentage of the larger person's bodyweight.

In the population tested, which had a body fat range of 21%-32%, having a higher percent body fat was not detrimental to performance. The three fastest subjects with the 41 kg load averaged 27.5% body fat, while the three slowest subjects averaged 23.0% body fat. The faster soldiers also had a greater fat free mass (47 kg) than that of the slower soldiers (42 kg). Apparently the greater fat free mass of the faster soldiers had a positive effect on their performance that outweighed any negative effect of their greater percent body fat.

In the stepwise multiple regression analysis for prediction of 3.2 km course time (Table 4), the APFT 3.2 km run time entered the regression model for each of the three loads. Absolute $\dot{V}O_{2\,max}$ entered the regression equation for both the 27 kg and 41 kg loads, while hip-width entered last into the equation for both the 14 and 27 kg loads. The number of push-ups the females could do in 2 minutes came into the equation to predict 41 kg load carriage course time.

Table 4. Regression Equations for 3.2 km Load Carriage Test

14 kg load carriage time, min = 1.8 (3.2 km run time, min) + 62.8 (shoulder width, m) – 45.4(hip width, m) -13.7 $R^2 = 0.82$
27 kg load carriage time, min = 1.7 (3.2 km run time, min) – 3.4 ($\dot{V}O_{2\,max}$, L/min) + 77.9 (hip width, m) -12.9 $R^2 = 0.73$
41 kg load carriage time, min = 2.2 (3.2 km run, min) + 0.12 (number of push-ups) – 3.4 ($\dot{V}O_{2\,max}$, L/min)+3.8 $R^2 = 0.69$

Discussion

This study has demonstrated that indices of aerobic fitness and body size are related to load carriage performance among women. This study is novel in that load carriage performance was evaluated using three different loads, with the 41 kg load being heavier than any load previously reported in the literature for women. The 41 kg load was deemed of particular relevance for the military, as it is typical of the load a solider must carry on a sustained march.

Maximal aerobic capacity related well to LCP at all three loads. Absolute $\dot{V}O_{2\ max}$ (L/min) was a better predictor of LCP than was relative $\dot{V}O_{2\ max}$ (ml/kg/min). This is not surprising because absolute $\dot{V}O_{2\ max}$ reflects both aerobic fitness and body size, while relative $\dot{V}O_{2\ max}$ reflects only the former. In addition, smaller people tend to have higher relative $\dot{V}O_{2\ max}$ because the ratio of arterial cross-sectional area to body volume decreases as body size increases (2). All else equal, larger, more muscular subjects, can carry loads more effectively than smaller, less muscular ones. Our data are in agreement with other studies also reporting that absolute $\dot{V}O_{2\ max}$ correlates more highly with LCP than does relative $\dot{V}O_{2\ max}$ (13, 21, 7).

As the measurement of maximal aerobic capacity requires laboratory equipment and personnel unavailable at most military installations, we also evaluated a surrogate and field expedient measure for aerobic fitness (i.e., self reported APFT 3.2 km run time). 3.2 km run time was more highly correlated than absolute $\dot{V}O_{2\ max}$ with LCP (Table 3). However, for the 27 kg and 41 kg loads, 3.2 km run time was only a slightly better predictor of load carriage run time than was absolute $\dot{V}O_{2\ max}$. As the load increased, the volunteers worked at a greater percentage of their maximal oxygen uptake (~50% of max with the 41 kg load [11]); thus the ability to predict LCP based on $\dot{V}O_{2\ max}$ is strongest with the heaviest load. The unloaded 3.2 km run test becomes less similar to the load carriage test as the load increases; thus the ability to predict LCP from 3.2 km run time is greatest with the lightest load. However the correlation coefficient for run time was greater with the 41 than the 27 kg load. Self-reported APFT 3.2 km run time was the best predictor of overall LCP for this group of women. Two studies by Kraemer et al. (15 and 14, the latter done on women) also demonstrated a relationship between 3.2 km run time and LCP (r=0.63 and r=0.60, respectively).

Body size, as represented by variables such as body mass, fat-free mass, fat mass, height and hip circumference, emerged as a consistent predictor of LCP with only the heaviest load. Body mass, height and hip circumference all positively correlated with fat free mass (r=0.93, r=0.68 and r=0.72, respectively). This indicates that the larger individuals had more muscle mass. Thus, it is likely that the larger women in this study were also stronger. Muscle tissue is estimated to make up 42% of fat free mass in the reference woman (3), and fat free mass is related to muscle cross sectional area which is proportional to muscle strength (23).

While we did not assess muscular strength in the current study, several other studies have shown a clear relationship between muscle strength and LCP. Isometric, isokinetic and isotonic strength of the torso and upper and lower limbs have been reported to correlate significantly with LCP (13, 7, 16, 22, 21). Additional support for the connection between muscle strength and LCP comes from studies demonstrating that strength improvements after several weeks of resistance training are associated with LCP improvements (15). Improvements in upper body strength with training have been suggested to be essential to improving the LCP of women (18). This finding may explain why push-ups came into the regression model for 41 kg load carriage course time; those individuals with greater upper body strength were better able to resist the tendency of the shoulder straps to pull the shoulders back causing discomfort and a biomechanically unfavorable walking position.

The role of fat free mass in LCP is seen more dramatically when its effect is removed via partial correlation. The correlations between run times with the 41 kg load and other anthropometric variables related to body size fell from good to insignificant when the effect of fat free mass was removed. The association between LCP and fat free mass has also been reported to be significant in other load carriage studies (13, 21, 16). In addition, correlations between absolute $\dot{V}O_{2\ max}$ and both 27 kg and 41 kg load carriage times were reduced when the effect of fat free mass was eliminated. For the 27 kg load, the coefficient for absolute $\dot{V}O_{2\ max}$ dropped to -0.46 from -0.61, and for the 41 kg load dropped to -0.52 from -0.70. Absolute $\dot{V}O_{2\ max}$ and fat

free mass correlated highly in this experiment (r=0.87), as it has in other studies (13, 7). Because a greater amount of active muscle tissue requires a greater amount of oxygen during exercise, absolute $\dot{V}O_{2\,max}$ relates to fat free mass. Therefore the correlation between LCP and $\dot{V}O_{2\,max}$ is partially influenced by fat free mass.

In this study, in which none of the volunteers were overweight, body fat was not found to be detrimental to LCP. In fact, increased fat mass was actually associated with shorter 3.2 km run times with the 41 kg load ($r=-0.53$, $p<0.08$). In addition, fat free mass and fat mass were positively correlated (r=.70); the volunteers who had greater fat mass also had greater fat free mass, presumably including muscle tissue. It is probably for this reason that subjects with greater fat mass were able to carry the extra fat without a decrease in performance compared to smaller, leaner subjects. Rayson et al. (21) also found in a group of men and women that greater levels of body fat were associated with better LCP with a 15 kg load. These findings can be explained by the positive correlation between adiposity and muscularity. (24, 17). However, because fat provides no benefit in itself to lifting or carrying heavy loads, it is likely that the subjects who did well carrying the backpack loads would do even better if they lost body fat, assuming that they could maintain their fat free mass.

It has been suggested that it takes a different body type to carry loads well than to be a good runner (10). As described above, larger more muscular individuals are more successful at carrying heavy loads, whereas the typical build of competitive middle to long-distance runners is lean and slight (20). The current study, however, showed good correlation between a 3.2 km unloaded run time and a 3.2 km load carriage time; individuals who carried heavy loads well also did well running unloaded. The volunteers had a relatively high overall fitness level. They were more aerobically fit than the average female according to normative data (1). $\dot{V}O_{2\,max}$ (ml/kg/min) ranged from 41.9 to 54.4, which represents the 80-99th percentile for females age 20 to 29.

In summary, the analysis described in this paper was an attempt to identify anthropometric and physical fitness variables that correlated with load carriage performance over a 3.2 km course. Absolute maximal oxygen uptake correlated well with 3.2 km load carriage time, across each of the three loads tested. The APFT, which is based on maximal number of sit-ups and push-ups performed and 3.2 km run time, made apparent its value for prediction of military physical performance. The 3.2 km unloaded run time APFT component was the best correlate of 3.2 km load carriage time for all three loads. Individuals of larger size and muscle mass are capable of carrying heavy loads (41 kg) faster than their smaller less muscular counterparts. Within the body composition range of our subjects, body fat does not appear to be a detriment to load carriage performance.

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